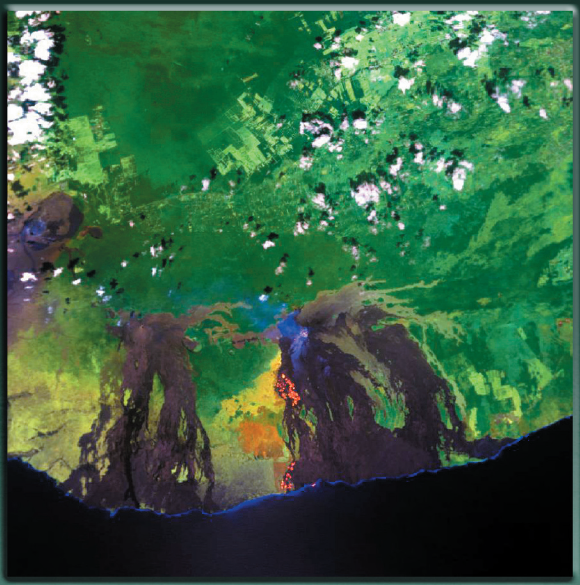
NASA EARTH SCIENCE ENTERPRISE

Suborbital Science Program FY03 Annual Report

JANUARY 2004



Cover Image:

The Puu Oo volcanic vent on the island of Hawaii, as imaged from the ER-2 aircraft with the MODIS Airborne Simulator (MAS.) This color composite of MAS bands 20, 10, and 2 (2.15um, 1.64um, 0.55um, as R-G-B) clearly shows the active lava flows in red; the cooled lava as dark, and the surrounding vegetation in green. A faint trace of the gaseous emissions can be seen as an overlaying blue haze. A more complex retrieval algorithm using infrared wavelengths indicates an extensive plume of SO_2 gas being emitted from the vent. Changes in the rate of SO_2 emission above or below the background rate indicate changes in the volcanic "plumbing" system and may lead to methods of predicting eruptions. (THORPEX Flight 03-619, 3/3/03.)

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Office of Earth Science, NASA Headquarters, Washington, D.C.

TABLE OF CONTENTS

FIGURES

TABLES

Introduction

The Suborbital Science Program in NASA's Office of Earth Science provides observational assets for obtaining Earth Science data. These assets include a suite of sustained, ongoing platforms and sensors on which investigators can obtain this data and that complement space-based observing systems. The Suborbital Science Program maintains these aircraft and sensor assets to support Earth Science Enterprise (ESE) program and science objectives, so that funded ESE investigators can have priority access to the facilities. The NASA assets have unique technical and operational capabilities that are not commercially available or viable. However, the program also facilitates access to other platforms or sensors for which data can be more readily obtained through commercial sources. In addition, the program is also constantly assessing new and evolving technologies to demonstrate their applicability for Earth Science data acquisition and to enhance the core capability over time.

This report highlights the significant accomplishments of the Suborbital Science Program in fiscal year 2003. This includes a summary of the missions and accomplishments of each of the aircraft under the program's direction, as well as a summary of program planning activities for UAV mission development, flight request management, outreach, etc. More information on the Suborbital Science Program can be found at: http://www.earth.nasa.gov/science/suborbital.

Mission Summary

FY2003 was a year of significant accomplishment for the Suborbital Science Program. A variety of flights, missions, and deployments were conducted over the continental U.S., Hawaii, Greenland, and Sweden supporting more than a dozen program managers in the Research and Applications Divisions and the six Focus Areas in the Office of Earth Science. Over 1300 hours of flight time were completed using the suite of airborne platforms available to the program. In addition, significant new capabilities in UAVs and advanced sensor development were demonstrated in 2003. Finally, suborbital science management processes are being assessed and improved. These accomplishments are summarized in the pages below.

Aircraft Missions and Accomplishments

SAGE III OZONE LOSS AND VALIDATION EXPERIMENT II (SOLVE II)

The NASA DC-8 participated in the SOLVE II from January 8 to February 6, 2003 in Kiruna, Sweden (Fig. 1). This experiment focused on acquiring correlative data needed to validate measurements from the Meteor-3M/Stratospheric Aerosol and Gas Experiment (SAGE) III satellite mission. The field campaign also acquired correlative measurements with the atmospheric chemistry instruments onboard the ADEOS-II and ENVISAT satellite missions.

Observations from previous campaigns and research over the last few years have improved the understanding of Arctic ozone losses, and have also revealed new areas of concern. As a result, SOLVE II developed priority science objectives to:

- Understand the polar ozone loss rate in early to mid-winter. Observations during the first SOLVE campaign showed a larger than expected loss of ozone during the January-February period. During SOLVE-II, DC-8 flights and balloon observations were designed to reexamine ozone losses during the January time frame.

- Validate the SAGE III instrument. SAGE III is the latest in a family of solar occultation satellite instruments designed to monitor distributions of stratospheric and upper tropospheric aerosol, ozone, water vapor, and other important chemically-active trace species with very high vertical resolution. The satellite observations are key components of the international effort to determine the current state of the ozone layer, and to determine how it will evolve into the future. Ozone, aerosol, water vapor, and nitrogen dioxide measurements from the DC-8 were compared to SAGE III measurements to prove the quality of satellite observations.

Fig. 1: DC-8 in Kiruna, Sweden.

- Improve our understanding of polar stratospheric clouds. Observations during the first SOLVE campaign revealed the unexpected presence of very tenuous polar stratospheric clouds (PSCs) (Fig. 2) composed of large particles in the high Arctic region. These large particles were shown to be composed of nitric acid and water and to contribute to ozone depletion. PSCs were again encountered on several SOLVE II flights.

- Improve our understanding of the chemistry of ozone loss. Arctic ozone is destroyed by chlorine and bromine gases that come primarily from humanproduced compounds. Measurements of these compounds during the first SOLVE campaign showed that the observed decrease of ozone was in reasonable agreement with the observed levels of chlorine and bromine. During the SOLVE-II campaign, DC-8 instruments tested observed ozone losses against these chlorine and bromine levels.

- Increase understanding of meteorological impacts on polar ozone levels. Over the course of the winter, ozone typically increases in the polar region as ozone rich air in the mid-latitudes and higher altitudes is carried pole-ward by the winds. This motion also acts to warm the polar region. Filaments of mid-latitude air, split vortices, and gravity waves were some of the interesting meteorological phenomena observed during SOLVE II.

Fig. 2: Polar Stratospheric Clouds.

SAGE III solar occultation measurements occur mostly at high latitudes in the Northern Hemisphere and mid-latitudes in the Southern Hemisphere. This coverage allows measurements to be made within the Arctic polar vortex where PSCs form and rapid ozone loss occurs locally in winter and early spring. At a latitude of 68^{o}N, Kiruna, Sweden, was chosen as the SOLVE II deployment site due to its proximity to the northern SAGE III occultation points and to the lower stratospheric polar vortex. It is also home to the Arena Arctica facility, a hangar designed for scientific aircraft operations and experiments at high latitudes.

The DC-8 deployed to Kiruna on schedule with a payload of 14 in-situ and remote sensing instruments, including the DC-8's own Information Collection and Transmission System (ICATS). Including test flights, 148 total flight hours were flown, with 9 to 10 hour science flights occurring every other day. Despite the challenges of icy runways, night conditions, and sub-zero temperatures, the DC-8 maintained a record of 100% readiness throughout the mission.

The majority of flight operations occurred between Sweden and Greenland, over the Greenland and Norwegian Seas. Several flights targeted a ground station at Nye Alesund on Spitzbergen Island. Two flights circled the North Pole. Many precisely timed occultation measurements were accomplished. Figure 2 shows one of many PSCs observed from the DC-8.

Fig. 3: SOLVE II aircraft.

Close collaboration between the DC-8 navigator and mission scientist allowed the flexibility to base each day's flight plan on on-going meteorological observations and modeling. The mission scientist was able to exploit the latest predictions for gravity wave activity and PSC formation.

SOLVE II was timed to coincide with the deployments of a Russian Geophysica M55 aircraft (as shown in Fig. 3, right) and the German DLR Falcon (Fig. 3, center) to Kiruna for the European sponsored Validation of International Satellites and Study of Ozone Loss (VINTERSOL) campaign. Several of the DC-8 flights originating from Kiruna were coordinated with the Falcon and Geophysica.

SOLVE II was co-sponsored by the Upper Atmosphere Research Program (UARP), the Atmospheric Chemistry Modeling and Analysis Program (ACMAP), and the Earth Observing System (EOS) of NASA's Earth Science Enterprise (ESE). For more information, view the SOLVE-II web site at: http://cloud1.arc.nasa.gov/solveII.

EOS AMSR VALIDATION

The Advanced Microwave Scanning Radiometer - EOS (AMSR-E) is one of six sensors aboard the EOS Aqua satellite, launched from Vandenberg AFB, California on May 4, 2002. AMSR-E is passive microwave radiometer, designed and provided by the National Space Development Agency of Japan (NASDA). It observes atmospheric, land, oceanic, and cryospheric parameters, including precipitation, sea surface temperatures, ice concentrations, snow water equivalent, surface wetness, wind speed, atmospheric cloud water, and water vapor. To assure the accuracy of these data sets, an extensive AMSR-E validation effort was planned by the AMSR science team.

Fig. 4: AMSR-E Validation Campaign Locations, 2000-2005.

The objectives of the AMSR-E validation efforts are assessment and refinement of algorithm performance and verification of data product accuracy. This is achieved through comparisons with in-situ data, satellite data, and model data. The AMSR-E validation program has two distinct phases: pre-launch and post-launch. Pre-launch activities are designed to demonstrate the science algorithm capability to retrieve valid science data products. Post-launch activities will continue to gather ground truth data through specific campaigns to meet the validation objectives. The validation activities are worldwide, as shown in the campaign location map of Figure 4.

The campaigns planned in 2003 included the Wakasa Bay Rainfall Validation, ASI, AASI, and the CLPX and SMEX experiments based in the U.S. These were all designed as multi-aircraft, multi-platform, interagency and international experiments, and address specific AMSR data products of precipitation, sea ice concentration, snow water equivalent and surface wetness.

The primary platform for the AMSR-E Validation was the NASA P3-B, because of its range, low-altitude capabilities, and especially for its large equipment bay that accommodates the microwave radiometers, which are key sensors of the validation campaign. The secondary platform was the NASA DC-8, because of its accommodation of the AirSAR sensor, which contributed active microwave data to the correlative data sets.

WAKASA BAY RAINFALL VALIDATION FIELD EXPERIMENT

The AMSR Rainfall Validation strategy recognizes that AMSR is one instrument in a sequence of improving instruments and capabilities over time. The validation plan is therefore to fill in the obvious gaps left in the earlier Tropical Rainfall Measuring Mission validation effort, notably rainfall outside the tropics. The Wakasa Bay Rainfall Validation experiment followed the ‘physical validation’ paradigm in which an error model of the measurement process is developed. It was a joint NASA and NASDA mission aimed at understanding the radiometric signals for very shallow rain systems and snow systems. The U.S. contribution was the P3-B aircraft, carrying a suite of microwave channels, plus newly developed instruments for unprecedented insight into cloud structures. The Japanese contribution consisted of a dual-polarization ground-based radar that put the aircraft observations into a meteorological context, plus supporting ground-based observations.

The P-3B arrived in Japan in early January, conducting its first science flight on January 14, 2003. A total of 12 science flights were completed before early departure to return to NASA Wallops Flight Facility for unscheduled maintenance prior to the CPLX mission.

ARCTIC SEA ICE FIELD EXPERIMENT

This arctic aircraft campaign integrated the requirements for obtaining the field data needed both for the validation of the standard AMSR-E sea ice products and for supporting ongoing studies of air-sea-ice interactions in Arctic coastal polynyas. Consequently, the EOS Validation Program and the ESE Cryospheric Sciences Program both supported the experiment.

The P3-B deployed to Alaska in March 2003, and completed seven aircraft flights (shown in Fig. 5) to validate the standard satellite products: sea ice concentration, sea ice temperature, and snow depth on sea ice. Regions covered included the Bering, Beaufort, and Chukchi seas, and flights were coordinated both with surface measurements at Barrow, Alaska, and at a Beaufort Sea ice camp with satellite overpasses that included not only the EOS Aqua AMSR-E sensor, but also Landsat-7, MODIS, RADARSAT, and ICESat.

The sensors carried by the P-3B for this mission included the NOAA/Environmental Test Laboratory’s Polarimetric Scanning Radiometers (PSR-A and PSR-CX), the NASA Airborne Topographic Mapper (ATM), and Turbulent Air Motion Measurement Systems (TAMMS). Digital and video cameras and infrared radiometers were included for ancillary data.

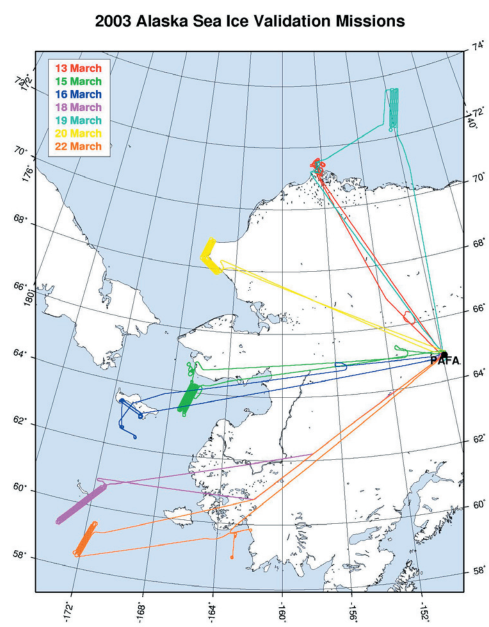

Fig. 5: ASI Missions Map. P3-B flights March 13-22, 2004. Polynas were observed on March 15, 16, and 22; all other flights measured various sea ice types coincident with ground and/or satellite observations.

THE COLD LAND PROCESSES FIELD EXPERIMENT 2003

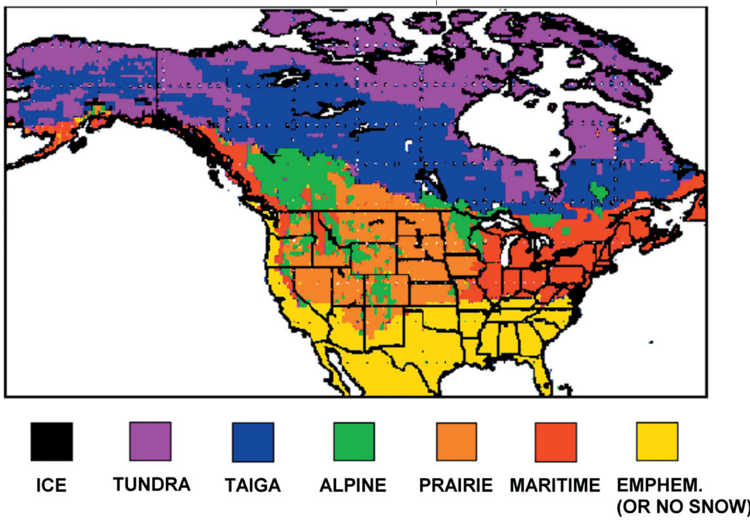

Fig. 6: Snow classes map. Region-scale snow classes derived from decision-tree model of snow type based on air temperature, wind speed and precipitation.

The Cold Land Processes Field Experiment (CLPX), sponsored by the NASA Land Surface Hydrology Program and the EOS AMSR Validation Program, studied the land component of the terrestrial cryosphere, the frozen landscapes of the Earth's land surface, where water is frozen either seasonally or permanently, and where snow, ice, and frozen soils and vegetation are common (Fig. 6). The CLPX Mission focused on developing the quantitative understanding, models, and measurements necessary to extend our current local-scale understanding of water fluxes, storage, and transformations to regional and global scales. To find out more about the Cold Land Processes Field Experiment (CLPX) go to: http://www.nohrsc.nws.gov/~cline/clp.html.

Cold land areas form a major component of the Earth's hydrologic system, and interact significantly with the global weather and climate system, the geosphere, and the biosphere. Seasonally and permanently frozen land surfaces affect cold climate engineering, human and animal mobility, and result in a variety of hazards and costs associated with living in cold lands.

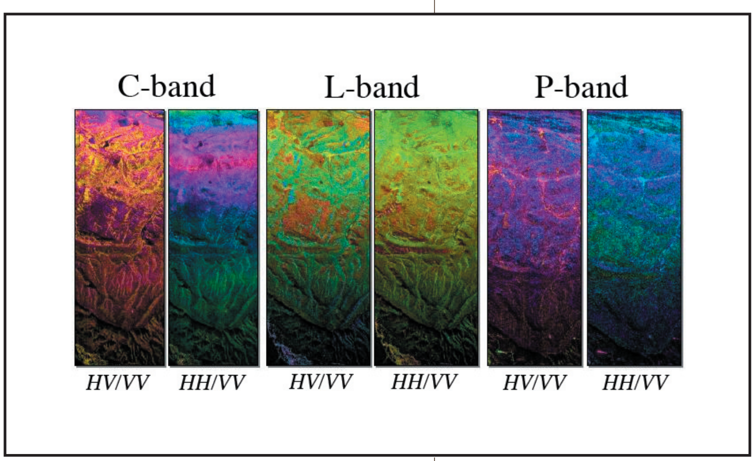

Fig. 7: North Park 360-1 multi-frequency polarimetry quick-looks from CLPX.

The objectives of this experiment were to:

- Understand the extent and evolution of snow and frozen landscapes and the impact on regional and global climate modeling.
- Improve measurement of snow properties over large regions.
- Determine how uncertainties associated with remote sensing observations constrain/affect data assimilation into models of cold land processes.
- Improve severe event forecasting.

The DC-8 deployed to Colorado Springs, Colorado, with JPL's Airborne Synthetic Aperture Radar (AirSAR), Polarimetric Scatterometer (PoleScat), and Wind Radiometers (WindRad). Measurements of snow pack characteristics and the freeze/thaw state of the land surface were made over the eastern Rocky Mountains, where a rich array of differing terrain, snow, soil, and ecological characteristics are provided (Fig. 7).

The experiment emphasized the development of a strong synergism between process-oriented understanding, land surface models, and microwave remote sensing.

Three intensive operations areas, manned with over 100 ground based scientists and observers, were the subjects of multiple coordinated flight line measurements. Close contact with ground personnel was maintained through direct radio communication with the DC-8.

The latest predictions for snowfall accumulation, temperature variations, and snow pack structure were taken into account for each day's flight plan due to the close collaboration between the DC-8 mission manager, navigator, and mission scientist.

A total of 100 flight hours, including test flights, were flown on the CLPX mission. A rigorous schedule of 9 to 10 hour science flights, scheduled every other day, combined with high winds and icing conditions made this mission particularly challenging. However, the mission accomplished all its science objectives.

SOIL AND MOISTURE EXPERIMENT 2003 (SMEX03)

Soil Moisture is the key state variable in hydrology: it is the switch that controls the proportion of rainfall that percolates, runs off, or evaporates from the land. Soil moisture integrates precipitation and evaporation over periods of days to weeks and introduces a significant element of memory in the atmosphere/land system. There is strong climatological and modeling evidence that the fast recycling of water through evapotranspiration and precipitation is the primary factor in the persistence of dry or wet anomalies over large continental regions during the summer. As a result, soil moisture is the most significant boundary condition that controls summer precipitation over the central U.S. and other large mid-latitude continental regions. The development of remote sensing technologies to facilitate a global soil moisture observing system is essential for providing the required wide-area soil moisture data needed for hydrological studies over large continental regions. NASA and the United States Department of Agriculture (USDA) are working together to test and validate the necessary scientific and technological advancements to make this global observing system possible. SMEX03 was part of this effort.

Fig. 8: DC-8 on tarmac at Will Rogers Airport.

SMEX03 supported NASA's Terrestrial Hydrology Program, the NASA Global Water and Energy Cycle Research Program, the EOS Aqua AMSR Validation Program, and the Special Sensor Microwave Imager (SSM/I). The P3-B supported all three parts of the SMEX03 mission, deploying to U.S. sites in Oklahoma, Georgia and Alabama in June and July. The DC-8 was deployed to Will Rogers World Airport, Oklahoma City, Oklahoma (Fig. 8) from June 19 to July 14, 2003 to participate in the Oklahoma

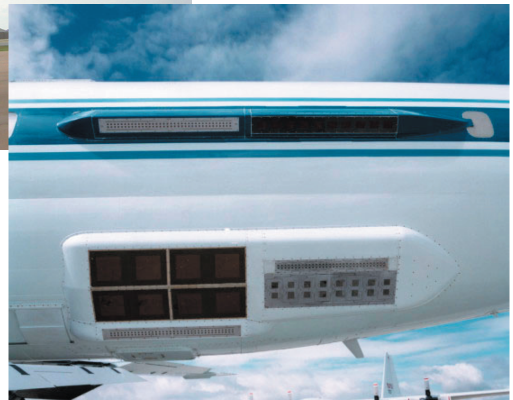

Fig. 9: Aft section of DC-8 at Will Rogers Airport (above) and close-up image of JPL Air SAR antennas mounted on the underside of DC-8 (right).

portion. These flights provided validation data for a wide range of vegetation conditions.

The objectives of SMEX03 were to understand land-atmosphere interactions, to extend instrument observations and algorithms to a broader range of vegetation conditions, to validate land surface parameters retrieved from AMSR data, and to evaluate new instrument technologies for soil moisture remote sensing. The specific goals for the aircraft were to:

- Collect passive and active data in near-coincident measurements between the two NASA aircraft; and

- Collect aircraft-based data concurrent with the Envisat satellite Advanced Synthetic Aperture Radar (ASAR) measurements, EOS Aqua AMSR, and with ground observations.

The externally mounted JPL AirSAR antennas can be seen in the Figure 9. This instrument operates at 450, 1260, and 5310 MHz (P, L, and C bands respectively) and can utilize both horizontal and vertical polarization modes in each band. The system can be also be configured to collect interferometric topographic SAR in the L and C bands. The P3-B configuration is seen in Figure 10.

SMEX03 flights took place over two large regional study sites including the extensively monitored Little Washita Experimental Watershed where ground teams

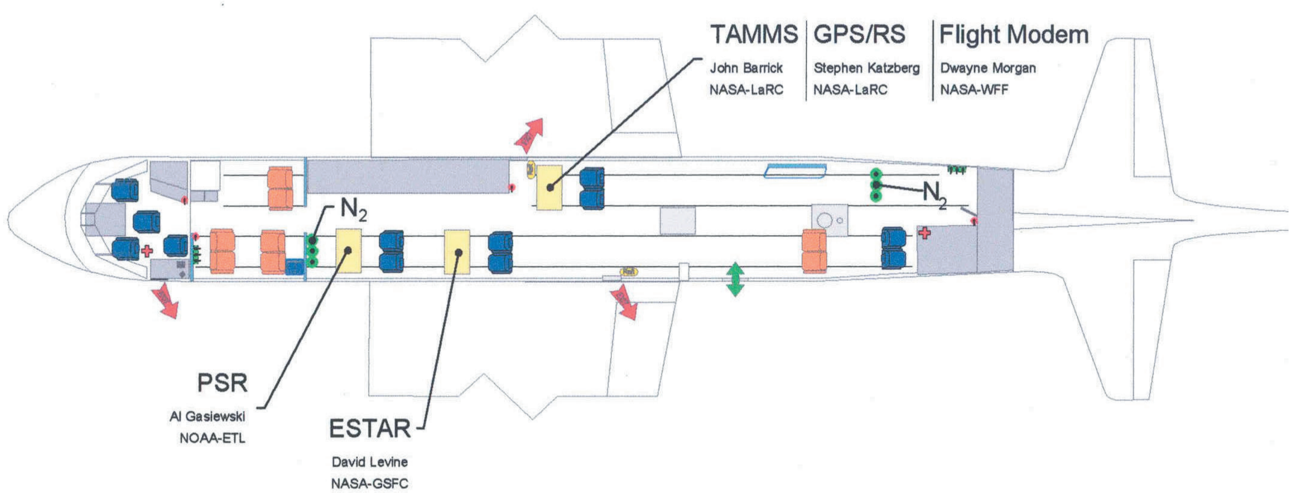

Fig. 10: P3-B payload configuration for SMEX03.

collected in situ samples on a daily basis. Five of the seven SMEX03 science flights were coincident with AQUA satellite coverage. Three of these flights were also coincident with as many as three other satellites, including Envisat.

THE OBSERVING-SYSTEM RESEARCH AND PREDICTABILIY EXPERIMENT (THORPEX) HAWAII 2003

In partnership with NOAA and the World Meteorological Organization/World Weather Research Program (WMO/WWRP), NASA's ER-2 is participating in a ten-year international, interagency research program, THORPEX. THORPEX is dedicated to improving short and medium-range predictions of high-impact weather (e.g., hurricanes, typhoons, and other high wind events) in the arctic, mid-latitude, and tropical regions.

The ER-2 was based out of Hickam Air Force Base, Oahu, Hawaii, from February 13 through March 22, 2003 for the THORPEX Regional Pacific Ocean Campaign. This Hawaii deployment site afforded an opportunity for coincident airborne and satellite sensor calibration/validation with the Terra and Aqua satellites over optically clear, open ocean (Fig. 11).

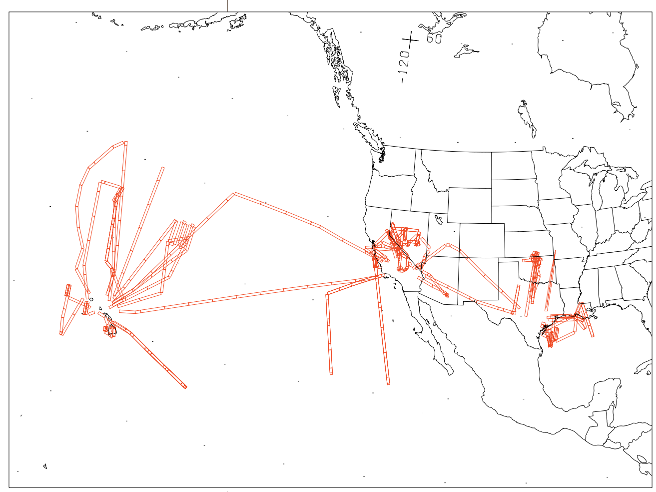

Fig. 11: ER-2 flight path coincident with satellite sensors.

The ER-2 sensor payload included:

- Cloud Physics Lidar (CPL), a laser used to acquire information about aerosol parameters and cloud microphysical structure and layering.

- Fast-Oz, a chemiluminescent instrument measuring ozone concentrations.

- MODIS Airborne Simulator (MAS), a modified Daedalus superspectral scanner acquiring imagery in the visible, near infrared, short wave infrared, mid, and thermal infrared (TIR) regions.

- NPOESS Aircraft Sounding Testbed Interferometer (NAST-I), a high resolution interferometer which measures radiance in the 3.6-17 μm region allowing retrievals of both atmospheric and surface temperatures, and water vapor profiles (Fig. 12).

- NPOESS Aircraft Sounding Testbed Microwave Radiometer (NAST-M), a passive microwave spectrometer that retrieves temperature and relative humidity profiles and cloud parameters (rain rate, particle size, cloud top altitude).

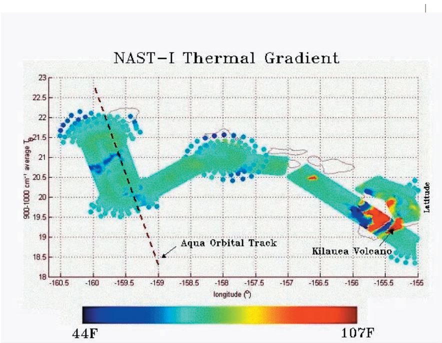

Fig. 12: NAST-I Thermal Gradient.

- Scanning High Resolution Interferometer Sounder (S-HIS), a high resolution interferometer that measures emitted TIR radiation in the spectral range of the 3-18 µm region. Data products include temperature and water vapor profiles, cloud top temperature and emissivity, trace gas concentration, land temperatures and SSTs.

The instrument payload allowed measurement of the surface properties of the ocean coupled with the changing profiles and physical parameters of the associated air masses and clouds moving across the Pacific. It is anticipated that a better understanding of the dynamics of the air-sea interaction in the northern Pacific (which directly impacts weather in North America) will lead to improving both storm genesis and predictive storm path modeling and improved military and civilian aviation forecasting.

The ER-2 flew approximately 50 hours in support of this highly successful campaign, which included coordinated flights with NOAA's G-4 aircraft. Scientists from both the NASA Goddard Space Flight Center and the Langley Research Center collaborated with researchers from University of Wisconsin, Massachusetts Institute of Technology, and NOAA.

THORPEX web site: http://angler.larc.nasa.gov/thorpex/.

ARCTIC ICE MAPPING (AIM)

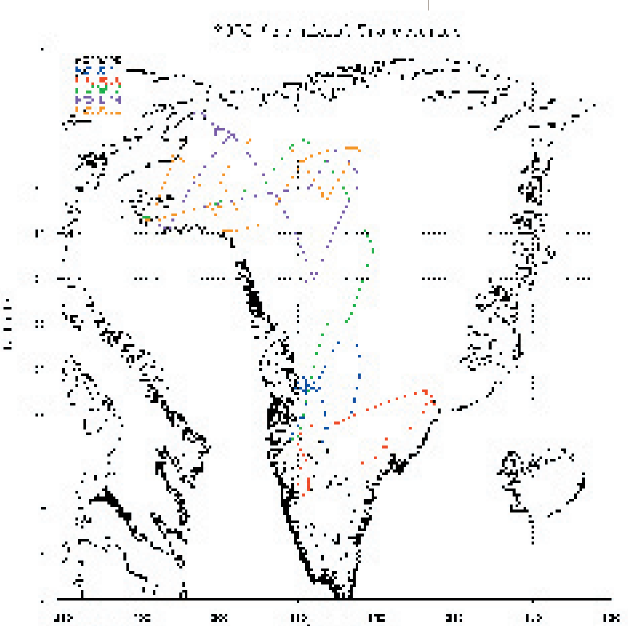

Fig. 13: Map of Greenland Trajectories.

The Arctic Ice Mapping (AIM) project completed its 2003 field trip to Greenland on the NASA P-3 in record time and within budget. Due to favorable weather conditions, the project was able to resurvey many flight lines in the margins of Southern Greenland that were observed to be thinning from the 1993-1998 flights. Intermingled with glacier surveys, ICESat satellite ground tracks were surveyed. These data are being used to calibrate and validate laser altimeter data from the GLAS instrument onboard ICESat. In addition, sites of interest to collaborating scientists from the University of Copenhagen were surveyed, supporting several graduate students. In 1993 and 1994, this project surveyed the entire Greenland ice sheet by airborne laser altimeter, obtaining surface-elevation profiles with root mean square (rms) accuracies of 10 cm or better (Krabill et al, 1995) along flight lines that crossed all the major catchment basins. The southern part of the ice sheet was resurveyed in 1998 (Krabill et al, 1999).

Flights were staged from Kangerlussauq in southwest Greenland, and Thule Air Base in northwest Greenland between May 7 and May 16, 2003. No aircraft problems were encountered during the deployment.

The primary sensors in this field mission were the Airborne Topographic Mapper (ATM-II), and a new version with wider scan capability, ATM-III. These are conically-scanning laser altimeters with a pulse repetition rate of 5-7 kHz and scan rate of 20 Hz, at an off-nadir angle of 15 degrees (22 degrees for ATM-III). Aircraft location is determined by kinematic Global Positioning System (GPS) techniques, and aircraft heading, pitch, and roll are measured by inertial navigation systems. At an aircraft altitude of 500 meters above the surface, a 250-m swath of data is acquired (400-m for ATM-III) comprising a dense array of 1-m laser footprints. Instrument biases and overall performance are checked during each flight by overflying flat surface areas (such as sea ice or fjords) and precisely surveyed portions of the airport. Additional checks are made on data consistency by comparing data at locations where flight lines cross and at stations on the ice sheet where surface-based GPS measurements were made. During repeat surveys, the airplane is navigated along the earlier flight lines by a GPS-guided autopilot, achieving cross-track separations typically less than 30 meters.

Fig. 14: The P-3 at Svalbard, Norway, the northernmost commercial airport in the world.

The aircraft was also instrumented with two ice penetrating radars from the University of Kansas (PI: Dr. Prasad Gogineni). These sensors measure to the bottom of the ice sheet, as well as internal layers within the ice.

Aircraft Summary: ER-2

Fig. 15: ER-2.

The ER-2 (Fig. 15) was developed for NASA to serve as a high altitude scientific research aircraft. The ER-2 designation was first applied to NASA's version of the U-2C model. NASA has since acquired and used the U2-R or TR-1 model, but has retained the ER-2 descriptor. The ER-2 differs from the U.S. Air Force's U-2 in the lack of defensive systems, absence of classified electronics, different electrical wiring to support NASA sensors, and, of course, a different paint scheme.

The ER-2 is an extremely versatile aircraft well suited to multiple mission tasks. The ER-2 is thirty percent larger than the original U-2 with a twenty-foot longer wingspan and a considerably increased payload over the older airframe. The aircraft has four large pressurized experiment compartments and a high capacity AC/DC electrical system, permitting a variety of payloads to be carried on a single mission. The modular design of the aircraft permits rapid installation or removal of payloads to meet changing mission requirements. The ER-2 has a range beyond 3,000 miles (4800 km); is capable of long flight duration and can operate at altitudes above 70,000 feet (21.3 km) if required.

Scientific instruments flown aboard the ER-2 can be mounted in various payload areas. On a single flight, the ER-2 can carry over one ton of instruments to altitudes above 65,000 feet and outside 95% of the Earth's atmosphere.

In addition to participating in the THORPex mission, the ER-2 conducted a number of local and targeted sensor flights during FY2003. These are summarized in the following paragraphs.

LOCAL AVIRIS FLIGHTS

The Airborne Visible Infrared Imaging Spectrometer (AVIRIS) has been flying in the Q-bay of NASA's ER-2 since 1989. AVIRIS was developed to facilitate earth remote sensing research across a broad spectrum of scientific disciplines: terrestrial ecology, geology, oceanography, limnology, atmospheric physics, and snow hydrology. The ER-2 can acquire AVIRIS data within a six-hour radius of NASA Dryden Flight Research Center (DFRC), which includes much of the Western U.S. With its 224 contiguous narrow spectral bands and 20 meter spatial footprint, AVIRIS data can be spectrally and spatially convolved to most optical satellite sensors. In addition to collecting individual PI science data during local DFRC campaigns, the ER-2 with AVIRIS can readily underfly satellite orbital paths. As with AirMISR, most of the bright target calibration/validation exercises involve field teams making in situ measurements. Calibration/validation target sites are Railroad Valley and Ivanpah Playa, Nevada, and Rogers Dry Lake, Edwards Air Force Base, California.

LOCAL AIRMISR FLIGHTS

The Airborne Multi-angle Imaging Spectroradiometer (AirMISR), flown in the nose of NASA's ER-2, is the airborne simulator for MISR on the Terra satellite platform. Local missions are associated with MISR calibration/validation field exercises typically at Railroad Valley and Ivanpah Playa, Nevada, and Rogers Dry Lake, California. In situ ground measurements of spectral optical thickness (sun photometer), bidirectional reflectance distribution function (PARABOLA), surface reflectance, and meteorological parameters (wind speed and direction, relative humidity, temperature) are acquired during the coincident Terra satellite and ER-2 flight. There is close coordination with the MISR field team, the AirMISR engineer, and the ER-2 pilots to ensure a successful campaign. AirMISR has been flying on the ER-2 since 1996.

LOCAL MAS FLIGHTS

The MODIS Airborne Simulator (MAS) instrument collected data on a series of missions in April to study the effects of diurnal heating and cooling, as they relate to land surface emissivity derivations.   Multispectral thermal infrared data were taken over a set of instrumented sites in California and Nevada during both the daytime and nighttime over-passes of the Aqua MODIS instrument. The experiment was repeated again in June, under the Terra MODIS, with a different set of soil moisture conditions. Precise timing and navigation with the ER-2 enabled these two very unique, cloud-free, day/night thermal data sets to be collected for the MODIS Science Team as they work to improve the accuracy of global surface emissivity retrieval algorithms.

Aircraft Summary: P3-B

Fig. 16: P-3B Orion Aircraft.

The Orion P-3B aircraft (Fig. 16), operated by the Aircraft Office and the Wallops Flight Facility (WFF), is a 4-engine turboprop capable of long duration flights of 8-12 hours, large payloads up to 15,000 pounds, altitudes up to 30,000 feet and true airspeeds up to 330 knots. Wallops has modified the aircraft with a “glass” cockpit or electronic flight instrumentation system (EFIS) and a flight management system (FMS). The FMS integrates redundant laser reference, inertial navigation and GPS position data onto composite cockpit CRT displays with weather radar and graphical flight plan overlays.

The P-3 missions flown in 2003 supported two major programs: the Advanced Microwave Scanning Radiometer - EOS (AMSR-E) and the Ice, Cloud and Land Elevation Satellite (ICESat). Field campaigns were conducted for precipitation, cold land processes, and soil moisture. For sea ice, both arctic and antarctic field campaigns were planned. All campaigns except the Antarctic Sea Ice (AASI) mission were concluded successfully.

The primary objective of the AASI campaign was to confirm the physical basis and range of applicability of the assumptions made in the AMSR-E sea ice algorithms and to establish the accuracy of the geophysical parameters derived from such algorithms. In the polar regions, the key parameters that will be archived as a standard product by NASA’s Earth Science Enterprise are: (a) sea ice concentration, (b) ice temperature, and (c) snow cover thickness. The campaign was the very first of its kind in the Antarctic region. Unfortunately, due to a P3-B aircraft malfunction, the AASI mission could not be completed, and has been rescheduled for FY2004.

The aircraft malfunction occurred on August 25, 2003 during the initial science flight of the AASI mission. Approximately 900 nautical miles from Punta Arenas, the base of the field campaign, the fuel pressure light began to flicker, but engine operations were normal. After approximately 15 minutes, the power indications began to fluctuate with the engine speeding up and slowing down, leading to the decision to abort the mission and return to Punta Arenas. Approximately 45 minutes to an hour later, the number 2 fuel pressure light began to flicker, and it too shortly began to fluctuate. The outside air temperature was –42C at altitude (21,000 ft). Suspecting ice in the fuel, the crew descended to 4000 feet to operate at a warmer temperature. Temperatures at 4000 feet were approximately –27C degrees. After about 30 minutes, while operating at 4000 feet, both engines functioned normally as the flight continued to return to Punta Arenas at 4000 feet altitude.

After landing, the plane was grounded while inspections were conducted and an incident investigation team formed. Inspections revealed debris in the fuel heater strainer inlets of engines #3 and #2. The debris was removed and the plane returned to WFF for further inspection and investigation. At WFF, additional debris was found in the boost pumps and pickup screens of engines #3 and #2. No damage was found on the incident engines or propellers.

An investigation team was formed to review the P-3 incident. Members of the team included representatives from aviation safety, engineering, aircraft operations, and aircraft maintenance.

The investigation team's findings were as follows:

- Extensive fuel tank maintenance had been performed on this aircraft in the last 3 years.

- Mission schedule pressure caused a "normalization of technical deviations." In other words, multiple patch leak repairs were chosen over more extensive, time-consuming repairs in order to meet mission schedules.

- Fuel heater strainer inlets on engines #2 and #3 were clogged.

- Because of this finding, it was likely that fuel tank pump screens were also clogged and bypassing contaminated fuel to fuel heater strainer inlets.

- Fuel tank technical orders did not require inspection of the fuel heater/strainer inlets.

- No anti-icing additive was used in the fuel during the flight.

Actions were assigned to address the findings prior to returning the aircraft to operations flight status.

Fig. 17: The inlet to the #3 Fuel Heater/Strainer unit. The debris shown is a mixture of sealant, fuel tank topcoat, and other debris. The debris was lodged in the inlet side of the heater, blocking the inlet to the heater tubes. The tubes are significantly blocked with debris.

Aircraft Summary: DC-8

Fig. 18: DC-8. Airborne laboratory in flight over snow-capped Sierra Nevada mountain Range.

The DC-8 (Fig. 18), operated by NASA/DFRC, is a medium altitude, moderate to high speed aircraft flying up to 41,000 feet above sea level between 425 and 490 knots True Air Speed (TAS). The DC-8 is capable of precise flight line navigation by means of an integrated inertial and GPS navigation systems from which line guidance is provided to the pilots. The aircraft can accommodate up to 30,000 lbs of scientific payload along with a complement of 40 on-board scientists and technicians. The DC-8 has a range of over 500 nmi and can fly science missions up to 10 hours duration. The aircraft and its complement of on-board sensors provide a readily deployable remote sensing platform that supports scientific research throughout the world.

DICE/LRR EXPERIMENT

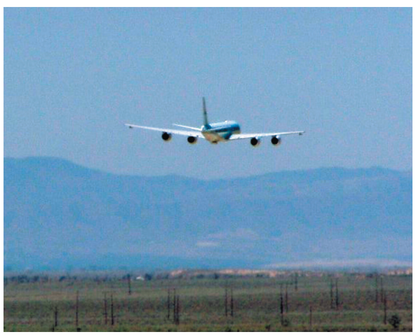

Fig. 19: DC-8 on take-off from Dryden/Edwards AFB.

The DC-8 Inlet/Instrument Characterization Experiment/Lightweight Rain Radiometer (DICE/LRR) was a May through June experiment that exploited the NASA DC-8 Airborne Laboratory's versatility. Three completely different objectives were pursued. Three separate investigations teams, supporting eleven experiment suites, were uploaded and flown simultaneously. Fifty-six individual investigators came from five contracting companies, six universities, four NASA centers, and NASA Headquarters. All objectives were met or exceeded, on schedule and within budget.

Many flight hours were devoted to flying below the boundary layer in both marine and desert conditions. A suite of instruments similar to those aboard the DC-8 was also installed on top of the Edwards AFB control tower. By exploiting the unique flight test-oriented culture of Dryden/Edwards, the DC-8 was able to sustain 200 foot altitudes for as long as 5 minutes and obtain in-flight data that cross-correlated to the tower measured data (Fig. 19).

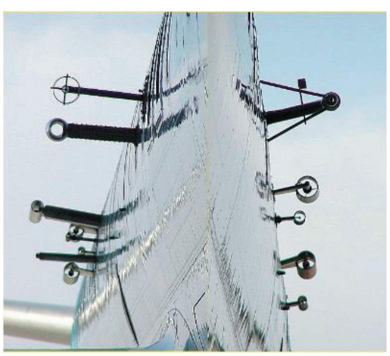

Fig. 20: This composite image of the left and right sides of the DC-8 illustrates many of the air sampling probe systems installed for the DICE/LRR Mission.

Several new and innovative in situ air sampling techniques were demonstrated during DICE/LRR (Fig. 20). A manifold interconnected all of the core DICE instruments so that each experiment suite could characterize each inlet. A new miniaturized semi-autonomous Light Detecting and Ranging (Lidar) instrument for measuring aerosols was flown for the first time and performed well. This was a major step in further reducing science packages to fit on medium-sized Uninhabited Arial Vehicles (UAVs). A new Chemical Ionization Mass Spectrometer from CalTech and a very large air probe from the University of Hawaii made their first high-speed flight debuts during DICE.

Flight test of the Lightweight Rain Radiometer X-Band (LRR) was the second objective. The LRR experiment is an Instrument Incubation Program development for a candidate technology supporting the Global Precipitation Mission (GPM) satellite. The LRR is a joint collaboration between the Goddard Space Flight Center and the University of Michigan. Operating at 10.7 GHz with a bandwidth of 30 MHz, this passive instrument is a proof of a concept for high quality rain measurements. NASA's rapid prototyping capability proved to be a critical advantage when shakedown flight-testing revealed that the carefully planned aerodynamic analysis and treatments were not effective. A large air dam fence from a previous experiment was fitted thereby resolving the issue with no loss of flights or delays in the project.

Fig. 21: DC-8 showing air dam fence.

Despite the name, the LRR is, in fact, a very large instrument package measuring 50 inches square and weighing nearly 1000 pounds. Aerodynamic interaction with other experiment fairings necessitated the employment of the air dam fence seen in front of the LRR (Fig. 21).
The third campaign objective was to complete the JPL Polarimetric Scatterometer (Polscat) experiment. The experiment, along with the complementary WindRad radiometer, were uploaded 2-1/2 months prior to DICE/LRR during the Cold Land Processes experiment campaign but had failed to execute its mission to calibrate and validate the WindSat satellite due to a persistent marine stratus layer over the target buoy in the Eastern Pacific. Finally, ideal conditions presented themselves during DICE/LRR and Polescat's objectives were met.

ALTM EXPERIMENT

The DC-8 supported the Airborne Laser Terrain Mapper (ALTM) Experiment between July 14 and August 8, 2003. The ALTM Experiment was part of the NASA Aviation Safety Program's Synthetic Vision Systems project.

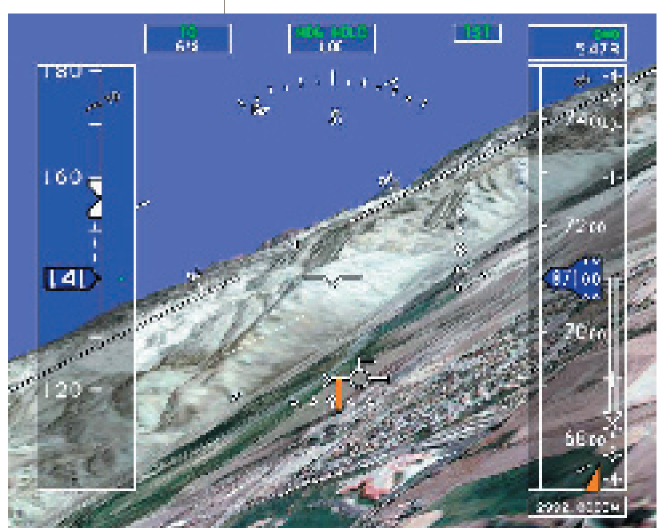

Fig. 22: TAWS and SVS imagery.

Terrain Awareness and Warning Systems (TAWS) and Synthetic Vision Systems (SVS) provide pilots with displays of stored geo-spatial data such as terrain, obstacles, and other surface features (Fig. 22). NASA is investigating SVS technology as an aid in averting two categories of possible accidents: Controlled Flight Into Terrain (CFIT) and Loss of Control (LOC). A primary causal factor leading to CFIT and LOC accidents is a pilot's loss of situational awareness, which includes spatial location and orientation relative to hazards such as terrain and obstacles. Interventions such as SVS and TAWS seek to improve this aspect of situational awareness, particularly in low visibility, by providing a virtual visual environment.

One of the problems facing TAWS/SVS however, is the lack of quantifiable integrity among the geo-spatial databases (models) used. This lack of integrity has limited certification and operational approval of TAWS/SVS to "advisory-only" systems for civil aviation. In other words, pilots must be able to trust that the virtual visual environment presented by SVS is a true representation of the actual environment. Furthermore, published obstacle data sets tend to suffer from a lack of completeness. One proposal as a possible mitigation to SVS integrity issues is to assess X-band weather radar. X-band weather radar has a reported ability to provide real time detection of terrain features such as ridge lines, obstacle locations, and runway edges.

The ALTM Experiment used laser terrain mapping technology to calibrate a commercial off-the-shelf X-band radar unit. The objective for the DC-8 was to collect high-resolution in-flight range measurements from the ALTM sensor to first-reflective surfaces (e.g., terrain, trees, buildings). Heights and locations of obstacles below the DC-8 were sensed, and Digital Elevation Models (DEMs) developed for the project were assessed.

The experiment's objective was successfully accomplished with flights over NASA Dryden Flight Research Center, the Reno/Tahoe International Airport, and over San Luis Reservoir in Central California. Four science flights were completed. The flights over Reno/Tahoe International Airport involved close coordination with tower personnel for the completion of multiple visual and instrument approaches and departures. Flights over the San Luis Reservoir with ALTM resulted in a complete DEM of the reservoir and its watershed.

The DC-8 payload for the ALTM Experiment consisted of the ALTM sensor and control rack (Fig. 23), and an X-band weather radar, which temporarily replaced the DC-8's own weather radar. The experiment also made use of an experimenter's radar altimeter and GPS receiver.

A total of 22 flight hours were flown for the ALTM Experiment.

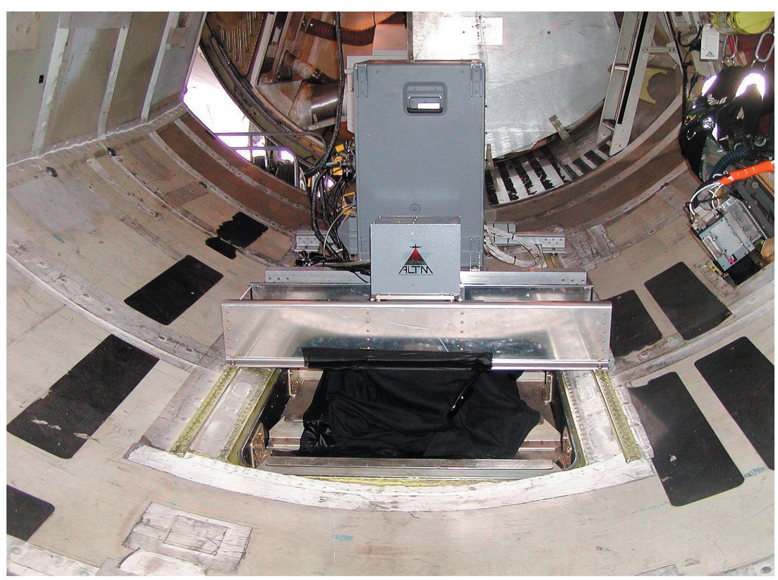

Fig. 23: ALTM sensor onboard DC-8.

Aircraft Summary: WB-57F

Located at JSC's Ellington Field are two WB-57F mid-wing, long-range high-altitude aircraft (Fig. 24). They are capable of operation for extended periods of time from sea level to altitudes in excess of 60,000 feet. Two crew members are positioned at separate tandem stations in the cockpit. The pilot station contains all the essential equipment for flying the aircraft. The sensor operator station contains both navigational equipment and controls for the operation of the payloads and payload support systems located throughout the aircraft. The WB-57 can remain aloft for approximately 6.5 hours, flying both day and night. With a range of 2,500 miles, the aircraft can be deployed to any continent. In addition to palletized payload accommodations in the under fuselage bay, the aircraft can support two wing pods, permitting payloads of up to 7000 lbs.

Fig. 24: WB-57F.

The JSC High-Altitude Research Program, which consists of the two WB-57 aircraft, conducted a 325 hour flight program in 2003, including 53 hours for the Costa Rican Airborne Research and Technology Assessment (CARTA) project. The EOS MODIS/ASTER simulator (MASTER) was installed with an ancillary RC-10 camera and during a three-week deployment to Costa Rica in March 2003, scanned over 70% of the country. Following data reduction, a three-day workshop was held in August with the Costa Rican science community to review data analysis and utilization, to enable future use and application of remote sensing data.

Aircraft Summary: Twin Otter

Fig. 25: Twin Otter aircraft.

The Twin Otter (Fig. 25) is a high-winged, unpressurized, twin-engine turboprop aircraft equipped with color weather radar, radar altimeter, dual GPS/Loran-C navigation systems with scientific data drops, and camera ports in the nose and belly areas. It is a highly maneuverable, versatile aircraft that can be flown slowly (80-160 knots/150-300 km/hr), in tight circles, and short take-off and landing (STOL). The aircraft is operated by Twin Otter International, Inc., which is located in Las Vegas, Nevada, and chartered by NASA.

The craft includes large and small camera nadir ports, autopilot and trackair aerial survey pilot display, echoflight satellite aircraft tracking, satellite phone communications and intercom for science team/pilot communications. The large cabin with its large access door allow the entry and mounting of NASA-developed sensors for remote sensing technique development and multi-scale process studies. The two instruments that have been accommodated to date are the Airborne Visible/ Infrared Imaging Spectrometer (AVIRIS) (Fig. 26) and the Airborne Topographic Mapper (ATM-II).

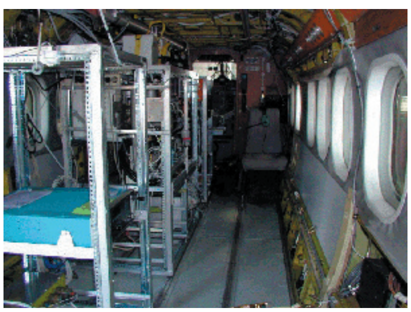

Fig. 26: AVIRIS payload on Twin Otter.

The AVIRIS is a unique optical sensor that delivers calibrated images of the upwelling radiance in 224 contiguous spectral channels from 400-1500 nanometers. The main objective of the AVIRIS project is to identify, measure, and monitor constituents of the Earth's surface and atmosphere based on molecular absorption and particle scattering signatures. Research with AVIRIS data is predominantly focused on understanding processes related to the global environment and climate change.

The ATM-II, a scanning LIDAR altimeter, measures topography to an accuracy of 10-20 centimeters by combining measurements from the laser altimeter (mounted over the belly camera port) and GPS receivers. The resultant high-resolution topographic maps are used primarily to detect temporal changes in the polar ice sheets, and to provide correlative data sets for the EOS ICESat satellite.

Aircraft Summary: B-200

The B-200 aircraft is an extensively modified Beechcraft King Air (Fig. 27), with two large nadir-viewing ports, a 1000 lb. payload, and an extensive avionics suite. It is operated by the DOE Remote Sensing Laboratory at Nellis Air Force Base, Nevada, and is currently the primary platform for the NASA MASTER instrument (MODIS/ASTER Airborne Simulator.) The Airborne Sensor Facility at Ames Research Center provides access to this U.S. Deparment of Energy twin-engine aircraft via an Inter-Agency Agreement. The B200 can fly at altitudes up to 35,000 ft., which produces a range of MASTER pixel sizes from 4 to 25 meters. Most missions this year were flown in the southwestern U.S., in support of the ASTER Science Team and their collaborators, and the Code YS Solid Earth program.

Fig. 27: Beechcraft King Air.

Aircraft Summary: Cessna Caravan

The Caravan (Fig. 28) is a high-wing single-engine turboprop aircraft with a large cargo compartment and a centerline instrument pod. It is owned and operated by Sky Research, Inc. of Ashland, Oregon, and is available for use by the NASA science community through the Airborne Sensor Facility. The primary application for this aircraft is very low altitude, low speed operations. It can carry in excess of 1000 lbs of payload at altitudes below 25,000. The MASTER instrument was integrated onto the Caravan this year, enabling pixel resolutions down to 2 meters for this infrared system; it also serves as a back-up for the B200 when flight schedules conflict. In addition, the Caravan was used this year by various other NASA programs testing UAV sat-com telemetry hardware and studying the environmental impacts of wildfires. It will soon be fitted with the commercial Hyvista Hymap hyperspectral scanner, which will then be available for the ESE science community.

Fig. 28: Cessna Caravan 208, in flight over Cenral Oregon. (Photo: Sky Research, Inc.)

Aircraft Summary: Aerosonde

Fig. 29: Aerosonde is launched from the top of car at Key West, Florida.

The Aerosonde (Fig. 29) is a single engine propeller Unmanned Aerial Vehicle (UAV) capable of long duration flights of 10–30 hours. It weights 30 lbs, has a 10 ft. wingspan, and is powered by a 24 cc fuel injected engine. The Aerosonde is capable of autonomous operation with a range of 1800 miles and a maximum altitude of 20,000 feet. Navigation is done using GPS. Communication systems include UHF and Iridium that allow the Aerosonde to be commanded and operated on a global scale. A unique capability of the Aerosonde ground control system is the Aerosonde Virtual Field Environment software, which is a web-based data display system that enables users to access data and monitor the progress of missions in real time from their own personal computers or office workstations. Users can also develop modified missions and upload these to the command center for implementation.

On board meteorological sensors measure temperature, humidity, barometric pressure and wind speed. An additional payload of up to 5 pounds can be integrated into the Aerosonde. Flight operations began at Wallops at the end of November 2003. Plans call for flights in FY04 to be short duration demonstrations of the Aerosonde's basic capabilities and then incrementally expanding the operating area and flight duration to include the National Air Space. Mobile deployments will also be demonstrated to show the Aerosonde Facility's capability to meet science needs anywhere in the world.

Aircraft Summary: Proteus

The Proteus is a unique airplane designed for a variety of potential applications that include operation as a long duration, high altitude sensor platform and as a test-bed for Uninhabited Air Vehicle (UAV) technology development. It has supported airborne science campaigns since March 2000. The Proteus can deliver experiments to altitudes up to 63,000 ft. and can fly for 16 hours with nominal payloads. Total payload capacity is 7260 lbs; however, there are performance trade-offs between payload and endurance or range. Nineteen kilowatts of electrical power is available for experiment use. The tandem-wing, turbofan configuration is modular in design and can carry payloads in a variety of internal and external configurations. The vehicle is normally operated with a two-person crew in a pressurized cabin. The second crew member adds operational flexibility and can be dedicated to running developmental payload systems. The autopilot can be configured to allow simulated UAV operations using remote commands from a ground station.

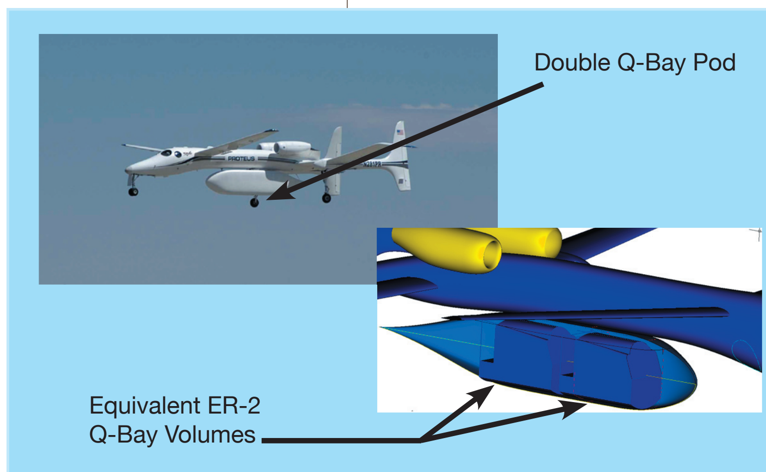

Fig. 30: Photo of Double Q-Bay Pod and illustration of equivalent ER-2 Q-Bay volumes.

The airplane was designed and built as a privately funded venture at Scaled Composite LLC's development facility in Mojave, California, and is operated exclusively by Scaled Composites. NASA established a Blanket Purchase Agreement (BPA) to facilitate use of the Proteus airplane for Earth Science applications beginning in 2003. A Payload User's Guide is now available which provides guidance to potential experiment designers.

A new payload carrier, referred to as the 'Double Q-Bay Pod' (Fig. 29) was developed and flight qualified in July 2003. This unpressurized pod was designed to replicate the volume and weight capability of two ER-2 Q-Bay compartments arranged in a fore and aft configuration. The structural and electrical interfaces for the Double Q-Bay pod are also identical to the ER-2 configuration. The objective of this design approach is to allow existing ER-2 experiments to integrate easily with the Proteus.

Other Proteus activities this year included flight tests to measure temperature and vibration characteristics in the payload compartments and to assess requirements for using the airplane as a platform for repeat-pass interferometry. These efforts along with other on-going experiment integration studies have been directed at making the Proteus more capable for airborne science missions and to serve as a transition vehicle leading toward more effective use of UAV platforms.

Other Program Activities

UNMANNED AERIAL VEHICLES

Fig. 31: Altus with ACES payload on ramp at Key West.

Fig. 32: Pathfinder+ over Kauai, Hawaii.

Exciting aerospace advancements in Unmanned Aerial Vehicles (UAVs) technologies have the potential to make suborbital observations in ways not possible today, particularly with durations that exceed 24 hours, and with the potential to fly for months at a time. These aircraft can also conduct missions that might be dangerous, without putting pilots or observers at risk. Autonomous technologies promise to expand the operational window, by providing UAVs the ability to track, analyze, and report emerging geo-physical events in near real time. UAVs have opened the air vehicle performance window to capabilities beyond what is possible with manned platforms, and promise to bring a new observational paradigm to airborne science.

Accomplishments of the UAV capability development project in FY03 include:

- Supported the First Response Experiment (FiRE), which identified the need for a mission capability that requires the cross cutting technologies that support a broad class of sub-orbital science missions. This included development of a high altitude imaging system, and a potential customer for UAV data.
- Worked with the U.S. Forest Service to develop improved sensing technologies and Decision Support Systems utilizing UAVs for long duration monitoring of wildfires.
- Worked with Department of Transportation to utilize UAVs for protecting the nation's transportation infrastructure.
- Developed mission concepts across Earth Science disciplines in concert with the Office of Aerospace Technology New UAV Initiative.
- Developed Lessons Learned for two UAV deployments conducted in 2002.
- Promote UAV applications that expand the UAV user-base, driving down costs, and increasing reliability, enabling a new observational capability for the Earth Science Enterprise.

In 2003, the UAV science demonstration program (UAVSDP) continued to support two projects: the Altus Cumulus Electrification Study (ACES) and UAV Coffee Experiment. (See page 33-35.) Both flight experiments were carried out at the very end of FY02, providing a wealth of information for activities in science data analysis, outreach and education opportunities, and an in-depth look at lessons learned from a science mission operations perspective. The ACES mission flew the Altus UAV from Naval Air Facility, Key West (Fig. 31). The UAV Coffee Mission flew the Pathfinder Plus UAV from the Pacific Mission Range Facility over the coffee fields of Kauai Coffee Company (Fig. 32).

These experiments demonstrated:

- The ability to fly high and slow, without typical concerns about weather, provided unique opportunities for remote sensing and in situ measurements.
- The opportunity to co-locate the science team and flight team on the ground proved valuable to real-time decisions on targeted way-points.
- Working with the FAA, proved that UAVs could be successfully flown in National Air Space, and with real-time modifications to the flight path approved.
- Working from a prepared implementation plan is appropriate for UAV missions.

Some important lessons for future missions:

- UAV flight services need to be less costly and more routine.
- Industry expansion with more vehicles and trained pilots is encouraged.
- UAV flights from civilian or non-military bases are desirable. Flying from military bases may be overly constrained.
- Technology development in the areas of payload miniaturization, telemetry improvements, and see-and-avoid systems is needed for future missions.

Both projects received NASA Group Achievement Awards in 2003.

During FY2003, UAVSDP activities focused on analysis and utilization of the scientific data acquired during flight. ACES results were submitted for publication in numerous peer-reviewed journals, notably an International Commission on Atmospheric Electricity (ICAE) special issue. Meteorology lesson plans were initiated on the basis of measurements and video from the field. Figure 32 shows a storm intensity map, developed from ground based radar sites, which was used for real-time flight planning. Coffee field imagery was used to enhance decision-making for the coffee harvest (Fig. 34). Data processing schemes and sensor functions were upgraded for future missions. Imagery was also incorporated into Geographic Information System (GIS) and remote sensing course work at Clark University.

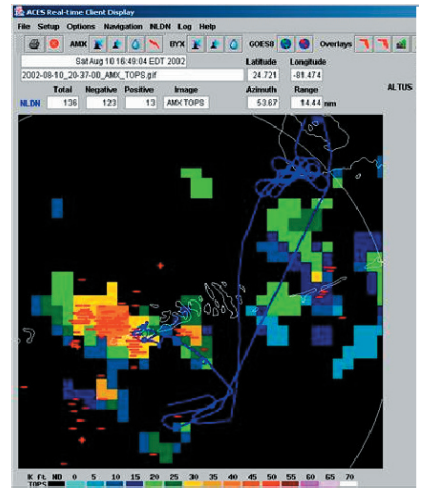

Fig. 33: Storm intensity map, ACES.

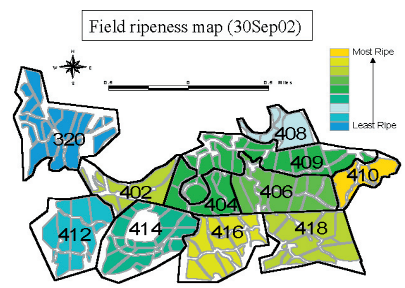

Fig. 34: Coffee ripeness map, decision support tool.

Airborne Sensor Activities

Fig. 35: Achefalya MAS image.

The Airborne Sensor Facility (ASF) provides a suite of common remote sensing systems made available to the NASA Earth science community through the flight request process. This year, we are also providing a sensor engineering and technology research support group, with the goal of enabling new observational systems.

UAV SENSOR TECHNOLOGY

One key sensor development area has been learning how to adapt the conventional sensor technologies used on manned platforms to the far more demanding environment of UAVs and Optionally Piloted Vehicles (OPVs). As part of this effort, three ESE legacy sensors, the TMS (Thematic Mapper Simulator), AOCI (Airborne Ocean Color Imager), and MAMS (Multispectral Atmospheric Mapping Sensor) are being rebuilt into a single modular UAV-compatible system that can be re-configured for different science applications. The goal is both to create a test bed for UAV operating paradigms and environmental packaging, and to provide an initial set of instrumentation for meaningful UAV science demonstrations as platforms become available.

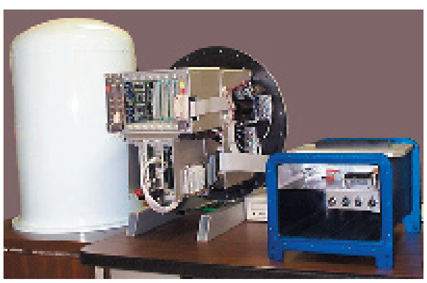

Fig. 36: Image of flight hardware and digitizer.

The modular system is built around a generic 16-bit data system that can be software-configured to capture data from a variety of imaging or non-imaging sensors. It features a pressurized electronics packaging to withstand severe operating environments (up to 70,000 ft.) with fully autonomous operation. It is also network-compatible for interfacing to other instruments, either on the same platform or across remote telemetry links. The external electrical and mechanical interfaces are intentionally simple, to enable easy migration across multiple platforms (e.g., Altair, Proteus, Global Hawk). One of the three imaging spectrometers can be mounted on a common fore-optic module. All are fitted with mechanically cooled infrared detectors (replacing the old LN2 dewars) to allow for unlimited mission duration. The spectral bands for the three spectrometers have been redefined based on input from the ESE community. For atmospheric research, water vapor bands at 1.38µm and 1.88µm will be included on TMS, and 6.7µm on MAMS. The MAMS will also include two of the thermal bands projected for the NPOESS VIIRS instrument. The AOCI will have all the bands of SeaWiFS, plus a thermal band for SST retrieval, providing high-resolution data for coastal and estuarine research.

COMMERCIAL PLATFORMS AND SENSOR DATA

As NASA seeks to out-source some of its suborbital data requirements, increased emphasis has been placed on building relationships between commercial providers and the ESE science community. An essential part of this effort is establishing practical and accountable mechanisms for access to these outside resources. Since 1996, the ASF has provided such a link to U.S. Department of Energy remote sensing aircraft, via an Inter-Agency Agreement. This year, an innovative relationship was established with a commercial platform provider, Sky Research. Access to their Cessna Caravan, and other platforms, was enabled through the combination of a Space Act Agreement, which allows them to operate from the Moffett Federal Airfield, and a NASA subcontract, which provides a funding mechanism. In 2003, the Sky Research Caravan was used to support the ERAST program, the joint NASA/University of Maryland Wildfire Response Team (Code YO) and the U.S. ASTER Science Team. The ASF also assisted in the preparation of a Request For Information seeking sources of commercial sensor data to further ESE research goals.

DATA COLLECTION MISSIONS AND SENSOR ENGINEERING

In parallel with these activities, the ASF continued to support ESE flight requests for MODIS and ASTER Simulator data, collecting approximately 425 flight hours of science data on four different aircraft (ER-2, B200, WB-57, and Caravan). (See Table 1) The MASTER instrument was integrated onto two new aircraft this year: the Cessna Caravan, capable of very low altitude operation, and the JSC WB-57, for a major deployment to Costa Rica. This sensor has now been installed and validated on five aircraft types, extending the concept of cross-platform compatibility and interface commonality. The MAS instrument underwent an extensive refurbishment, which included replacement of most of its reflective and transmissive optical surfaces. Extensive use in the high altitude ER-2 environment had caused significant degradation in optical throughput. As a result of the refurbishment, signal-to-noise performance in many channels was increased two-fold.

	ASF Sensor Utilization PY 2003 (Hours)		
	MAS	MASTER	RC-10/30
Code YS/YO	92	3	134
EOS	74	44	63
Other NASA	--	--	12
Reimbursable	--	91	82
Total Hours:	166	138	291

Table 1: ASF Sensor Utilization.

CALIBRATION LABORATORY

The ASF calibration lab was augmented with the addition of to new precision radiance sources: a second 30” integrating sphere with the new Spectraflect coating, and a high-temperature blackbody source. The latter, unique in the EOS community, will be used to better characterize IR instruments for hot target temperature retrievals (e.g. biomass burning and lava flows.) The lab again participated in an EOS “round-robin” exercise, in which sources from NIST, GSFC, University of Arizona, and Ames are inter-compared. The large environmental chamber was enhanced by interfacing it to the main optical bench, allowing instruments to be fully calibrated at in-flight temperatures down to -50 C.

COLUMBIA ACCIDENT RESPONSE

The ASF was requested to assist with a large-area aerial survey of the Space Shuttle Columbia debris field. The NASA Itek Iris-II panoramic reconnaissance camera was removed from storage, quickly repaired and tested, then flown over the disaster site on the ER-2. A total of 2,400 ft. of film was collected, with a nominal ground resolution of eight inches. Processing was arranged through the U.S. Air Force (USAF), and a photo analysis team was rapidly assembled, calling on experts from USGS, USAF, and NIMA. Results were fed directly to the search teams in the field. Approximately 15 previously undetected large objects were identified for ground investigation.

Flight Requests

Allocation of Suborbital Science Program assets is managed through the Flight Request Process, which is initiated each year through the annual call letter. A total of 94 requests were approved in FY03, about 50% of the total submitted. Over 1300 flight hours were completed among the various airborne science platforms. Table 2 provides a summary of FY03 flight requests and flight hours.

	Fiscal Year						
Aircraft	**98**	**99**	**00**	**01**	**02**	**03 (Estimated)**	**04 (Projected)**
DC-8	414	527	571	330	279	407	350
ER-2	489	542	651	443	366	350	440
P-3	163	388	8	302	182	392	234
WB-57	135	355	304	293	441	325	400
Twin Otter	--	134	181	355	172	266	200
B-200	79	136	110	146	77	56	70
Annual Total	1280	2082	1825	1869	1517	1796	1704

Table 2: FY03 flight requests and flight hours.

Table 3 is a historical summary of flight hours by aircraft and fiscal year.

	Flight Requests		Flight Hours		
Aircraft	**Submitted**	**Approved**	**Approved**	**Completed**	**"Carry-over"**
DC-8	52	29	525	407	2
ER-2	41	26	602	350	178
P-3	16	9	626	392	113
Twin Otter	46	14	18	108	103
B-200	21	10	80	56	22
Other	13	6	263	?	?
Total	189	94	2274	1313	418

Table 3: Historical summary of flight hours.

In addition, several management changes to the flight request process were implemented in FY03, including the development of a revised Flight Request Management Plan. The purpose of these changes was to develop a consistent review, approval, and close-out approach to suborbital science flight requests (FRs), to document the FR approach and processes for management and PI teams and to provide timely FR status reporting to NASA Headquarters. Work also continues on developing an enhanced flight request tracking database.

Flight Request web site: http://www.dfrc.nasa.gov/Research/AirSci/index2.html

Education/Outreach Activities

During FY03, ESE developed both education and outreach/communication plans consistent with the agency mission “to inspire the next generation of explorers.” The Suborbital Science Program is adapting its education and outreach activities to align with the guidance provided in these plans. Suborbital projects are particularly suitable for education and outreach since: (1) as deployable/retrievable assets, the public has direct exposure to the equipment, and students have hands-on experience with sensors, (2) suborbital science emphasizes the local and regional phenomena with which the target audience is most familiar while providing the connection to the global datasets from NASA’s orbital assets, and (3) the Earth and environmental science has broad public support and appeal.

Suborbital education and outreach activities fell into three categories during FY03: mission-related, exhibits at conferences/public events, and workforce development.

MISSION-RELATED EDUCATION/OUTREACH

The SOLVE II, CARTA, ACES and CLPX missions had specific education and outreach activities associated with the science objectives of their campaigns. The SOLVE II mission conducted lectures and tours with the local general population at the deployment site and developed an educational outreach section as an element of its mission website. CARTA mission personnel conducted remote-sensing data interpretation classes with the Costa Rican science community. ACES developed K-12 interactive lesson plans that permit students to follow the science team’s field activities, evaluate the daily conditions/results and make campaign decisions. CLPX conducted real-time webcasts between the CLPX mission scientist and multiple K-12 schools nationwide, permitting students to interact directly with the science team. These webcasts were part of a series associated with the EOS Aqua satellite. Also, outreach webpages are being developed for all Earth Science Project Office (ESPO)-managed missions. This includes the development of Spanish language content pages for outreach to the Hispanic and Latino community.

EXHIBITS

The Suborbital Science Program supported the agency Centennial of Flight activities, providing the ER-2 for static display at the Experimental Aircraft Association’s annual AirVenture event in Oshkosh, WI. The program also exhibited and staffed a multi-panel display featuring suborbital science activities at both the spring and fall American Geophysical Union (AGU) meetings.

WORKFORCE DEVELOPMENT

In FY03, DFRC began a program with the InterAmerican University to develop a pipeline for future mission managers. A professor in the School of Aeronautics, Mario Signoret, joined the Airborne Science program as an IPA Assistant Mission Manager to learn expeditionary mission management and to develop a follow on undergraduate university course to be taught at DFRC in the summer of 2004. DFRC completed the curriculum and tested it with a Graduate Education for Minorities (GEM) student from the University of Colorado. Figure 37 shows the GEM student learning mission management “hands-on”. Her input provided valuable insight for improving the content curriculum.

Fig. 37: GEM Student Juniper Jairala of the University of Colorado and Visiting Professor Mario Signoret of the InterAmerican University in Puerto Rico at the DC-8 Mission Director’s Console during the SMEX campaign.

FY2002 Highlights

Although the focus of this report is FY2003 accomplishments, three missions conducted during FY2002 were of such substantial scope and effort that they deserve special mention. These missions were the CRYSTAL-FACE mission, conducted from Key West, Florida, in July 2002, the ACES mission, also conducted from Key West, in August 2002, and the Coffee Harvest Optimization Project conducted from Pacific Missile Range Facility, Hawaii, in September 2002.

Although the focus of this report is FY2003 accomplishments, three missions conducted during FY2002 were of such substantial scope and effort that they deserve special mention. These missions were the CRYSTAL-FACE mission, conducted from Key West, Florida, in July 2002, the ACES mission, also conducted from Key West, in August 2002, and the Coffee Harvest Optimization project conducted from Pacific Missile Range Facility, Hawaii, in September 2002.

CRYSTAL-FACE: Cirrus Regional Study of Tropical Anvils and Cirrus Layers - Florida Area Cirrus Experiment

Two effects of greenhouse warming are an enhancement in clouds and an increase of water vapor in the atmosphere, both of which alter the characteristics of upper tropospheric cirrus clouds. The role of clouds and water vapor in climate change is not well understood; yet water vapor is the largest greenhouse gas and directly affects cloud cover and the propagation of radiant energy. In fact, there may be positive feedback between water vapor and other greenhouse gases. Carbon dioxide and other gases from human activities slightly warm the atmosphere, increasing its ability to hold water vapor. Understanding these complex interactions is essential for the successful modeling of the Earth's climate and in determining the eventual overall effect of manmade greenhouse gases.

The CRYSTAL-FACE mission, led by NASA was a major, highly successful, multi-agency campaign designed to help improve our regional and global climate models. In addition, the measurements will also play a crucial role in providing validation opportunities for the Terra, Aqua and TRMM satellite cloud property algorithms, and will support development of the future satellite retrieval schemes of CALIPSO, CloudSat, and EOS-Aura.

For this well coordinated study of our environment, NASA brought together six research aircraft, three ground sites and an international team of over 450 top scientists from seven NASA centers, the National Oceanic and Atmospheric Administration, the National Science Foundation, the Department of Energy, the Office of Naval Research, the U.S. Weather Research Program, universities and other government agencies.

Based from Key West Naval Air Facility in July 2002, the research aircraft were flown over three ground sites while collecting detailed in situ and remote sensing measurements of aerosols, ice crystals, radiative fluxes, gas concentrations and meteorological characteristics of the convective systems in the south Florida region. The sites and platforms were equipped with over 100 state-of-the-art instruments gathering an unprecedented set of measurements that will be compared with both satellites and the results of advanced atmospheric models.

Fig. 38: CRYSTAL-FACE mission support aircraft in the hangar at the Naval Air Station, Key West, FL. From left to right: NASA ER-2, Scaled Composites Proteus, NASA WB-57, CIRPAS Twin Otter, and UND Citation.

Figure 38 details the aircraft used in the mission, which included:

- The NASA ER-2 based at Dryden Flight Research Center.
- The WB-57 based at Johnson Space Center.
- The Proteus Aircraft, owned by Northrop Grumman and operated by Scaled Composites.
- The Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS), associated with The Naval Postgraduate School in Monterey, California, providing the DeHavilland UV-18A "Twin Otter" aircraft.
- The Cessna Citation II aircraft operated by the University of North Dakota.
- The Naval Research Laboratory P-3 aircraft with the NSF ELDORA radar installed.

CRYSTAL-FACE was one of the largest multi-agency atmospheric sciences field campaigns ever conducted. It is a prime example of NASA's Earth Science expertise in achieving such a significant scientific accomplishment and has become a role model for how future airborne science campaigns should be conducted.

For additional details and results from the mission, please visit the CRYSTAL-FACE web site at: http://cloud1.arc.nasa.gov/crystalface/.

ACES - Altus Cumulus Electrification Study

The Altus Cumulus Electrification Study (ACES) was a science experiment designed to investigate the life cycle of thunderstorms in the vicinity of the Florida Everglades using an Uninhabited Aerial Vehicle (UAV). Based out of the Naval Air Facility Key West (NAFKW), the field campaign phase of this project was successfully conducted during August 2002. The UAV represents an exciting new platform that can contribute in significant and unique ways to lightning and storm observations. In turn, these types of measurements can be linked to global scale processes (e.g., global water and energy cycle, climate variability and prediction, atmospheric chemistry) to provide an improved understanding of the total Earth system.

The primary science objective of ACES was to investigate lightning activity and its relationship to the microphysical and dynamic properties of summertime thunderstorms. Using a complement of electrical, magnetic, and optical sensors, the ACES results are increasing knowledge of storm processes, which leads in turn to advancements in weather forecasting and the field of atmospheric electricity. The information obtained from this mission is serving to validate observations provided by space-borne lightning sensors, characterize the electromagnetic interaction between thunderstorms and the ionosphere, improve rainfall algorithms, and diagnose and forecast severe weather events.

The ACES experiment flew 13 flights, collecting over thirty hours of electric field and meteorological data in the vicinity of thunderstorms in south Florida. The Altus UAV was able to fly over and around the weather of interest because of its altitude and endurance capabilities. It is also electrically quiet, a good feature for meteorological missions. A unique feature of the ACES mission was the ability to indicate the location of the aircraft onto a real-time weather display of real-time (Fig. 39). The software for this visual aid, developed at MSFC, is now available for other users, UAVs or other aircraft.

ACES was led by a team from NASA Marshall Space Flight Center (MSFC). Other major participants were at NASA Goddard Space Flight Center and Pennsylvania State University.

For additional details and results from the mission, please visit the ACES web site at: http://aces/msfc.nasa.gov/index.html.

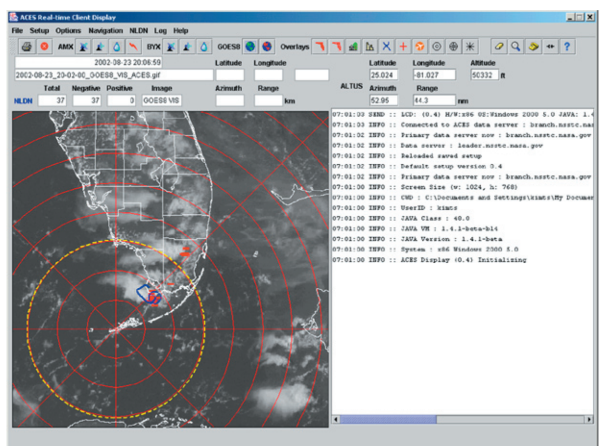

Fig. 39: ACES Display Screen Showing location of Altus Relative to Weather.

UAV COFFEE HARVEST OPTIMIZATION

In September 2002, NASA's solar-powered Pathfinder-Plus (PF+) UAV conducted a successful proof-of-concept mission over the Kauai Coffee Plantation (KCP), Hawaii. AeroVironment flew PF+ from the Pacific Missile Flight Range (PMRF) to determine from visible and infrared signatures the ripeness of coffee cherries in individual fields. While in U.S. National Airspace, the transponder-equipped PF+ was supervised by Honolulu air traffic controllers and treated like a conventionally-piloted aircraft. Two high spatial resolution multispectral digital camera systems were housed in exterior-mounted environmental chambers, and were controlled from a ground station established at KCP. During the four hour flights above KCP, PF+ exhibited the ability to navigate pre-planned flight lines, as well as perform spontaneous maneuvers to collect imagery in cloud-free areas. A line-of-sight telemetry system using unlicensed radio frequency enabled rapid image download at rates exceeding 5 MBps. All images were thus available for viewing, enhancing, and printing shortly after collection. Despite persistent cumulus cloud cover exceeding 70% during the image collection period, the loitering and maneuvering capability of PF+ ultimately enabled collection of cloud-free imagery over virtually all of the harvest-ready acreage. Relative field ripeness was predicted by tree canopy visible-region reflectance. The grower used decision support products, which included a thematic map and tabular listing, to guide ground-based ripeness assessment and sequencing of harvest operations. During part of the flight, payload control was relinquished to an operator located on the U.S. mainland at a distance of 4500 km. The mission demonstrated the capability of the solar-powered UAV, equipped with miniaturized imaging systems, to collect and quickly deliver high-resolution imagery over a localized region for an extended time period (Fig. 40).

Clark University and a team from NASA Ames Research Center (ARC) led the UAV Coffee Harvest Optimization experiment. Payload development was performed by the ARC team and included efforts by California State University - Monterey Bay and Kauai Airborne Sciences.

For additional details and results from the mission, please visit the UAV Coffee web site at: http://www.clarku.edu/research/access/geography/herwitz/herwitzD.shtm.

Fig. 40: Composie of high resolution visible imagery obtained by Pathfinder+ over Kauai Coffee Plantation.

Future Planning

This Suborbital Science Program supports NASA/ESE's basic science need for new remote sensing technique development, satellite sensor cal/val, and multi-scale process studies for development and validation of predictive models using satellite data. The program is in transition with the intention to transfer routine suborbital data collection activities to partners and industry, and to direct NASA efforts toward infusing new platform and sensor technologies that lead to future revolutionary sets of suborbital observational capabilities.

PROGRAM BUDGET CHANGES

During the FY04 budget formulation and approval cycle, the Agency developed a new Strategic Vision/Mission that is focused on scientific exploration and discovery 'as only NASA can.' In the same time period, the Earth Science Enterprise had to deal with issues in its space mission program that required priority decisions. Taken together, the result to the Suborbital Science Program was a significant reduction in scope for the established program, plus specific guidance to develop a unique Suborbital program that exploits NASA's contributions to Earth Science, i.e., an end-to-end research approach that utilizes unique global observations taken from aerospace technology-enabled vantage points.

PROGRAM RESPONSE

Various alternatives considered for revamping the program, which included reducing the number of platforms, changing the platform complement to less expensive platforms, and establishing periodic community review of existing platforms for continued inclusion in the program. To incorporate, within the budget constraints, both program evolution toward new capabilities and accomplishment of our science objectives in near-term field experiments, the program's fundamental strategic values and objectives were re-examined.

As a result, the Suborbital Science Program has been refocused to development of new suborbital and airborne technologies, working with technology development partners (e.g., Code R, ESTO) to "on-ramp" new capabilities, and with operational and research partners (e.g. NOAA, industry, NSF, etc.) to "off-ramp" established capabilities for the Earth research and applications community to alternate sources or operations.

NEW PROGRAM IMPLEMENTATION

The approach to implementing the new program is based on minimizing in-house assets and increasing competitive review. This is intended to foster innovation by reducing dependence on existing (and increasing aged/outdated) infrastructure while simultaneously inviting new ideas. The new programmatic architecture consists of three program elements: A science element that develops requirements for new suborbital capabilities and supports suborbital missions based on the science roadmaps; a platform element that experiments with new platform capabilities to demonstrate scientific value to the research and applications communities; and a catalog element that adapts off-the-shelf capabilities for innovative research. The Enterprise's six Focus Areas drive the requirements and the definition of the first element, and the requirements of the first element, in turn, drive the contents of the other two elements.

The science element is the core of the program, maintaining relevance to the Enterprise science focus areas through participation in the roadmap reviews. The primary purpose of this element will be to define suborbital science requirements, which can be further developed into suborbital experiments, aeronautics requirements for platforms, and/or new sensors.

The experimental platform element enables infusion of new aeronautics technologies into the Earth Science community. It is primarily implemented through partnerships with technology development programs that will advance selected technology platforms to operational status, adapting them for Earth observation purposes.

The catalog element is also expected to use cooperative and interagency agreements, task-order and Indefinite Delivery Indefinite Quantity (IDIQ) contracts and other innovative management structures that minimize NASA infrastructure. The objective of this third element is to provide flexible, on-call access to the widest possible range of proven suborbital and airborne observing capability. This element replaces the original Suborbital Science Program content with less infrastructure liability.

TRANSITION APPROACH AND TIMELINE

The target date for the new program structure to be fully implemented is 2008. The date was based on the 5-year planning window from the decision to restructure the program. During that 5-year window, a number of suborbital campaigns are in the planning stages, and the transition approach is to support these campaigns as much as possible. To protect these near-term science investments, the projects were directed to maintain basic capabilities at reduced levels while exploiting partnerships within and outside NASA to identify potential operational off-ramps for existing, proven capabilities. Funds saved through partnerships are to be reinvested in exploratory use of new platforms now available, e.g., Proteus and UAVs, such as Aerosonde.

Aircraft mission and campaign requirements are continually collected and assessed against the expected availability of the suborbital capabilities. Table 4 is the latest 5-Year Plan maintained by the program. This table shows the major earth science missions identified through FY08.

Missions	Location	Aircraft	FY 04				FY 05				FY 06				FY 07				FY 08			
			FQ1	FQ2	FQ3	FQ4	FQ1	FQ2	FQ3	FQ4	FQ1	FQ2	FQ3	FQ4	FQ1	FQ2	FQ3	FQ4	FQ1	FQ2	FQ3	FQ4
Atmospheric Composition																						
INTEX	NH, IL Western U.S.	DC-8, J-31 DC-8, P-3				↔						↔										
Aura Val (AVE)	TX, Costa Rica TX Sweeden Australia TX, Costa Rica TX TX, Costa Rica	WB-57 WB-57 DC-8 WB-57, Prot WB-57 WB-57 WB-57		↔			↔	↔				↔		↔			↔		↔			
TWP	Guam Guam?	ER-2 ER-2, WB-57, DC-8										↔					↔					
TRACE-P Next	Japan, Guam?	DC-8?, P3?																	↔	↔		
Climate																						
AIM/ICESat	Norway Norway Norway	P-3 P-3 P-3			↔				↔				↔									
Antarctic Sea Ice	Chile	P-3				↔	↔															
Arctic Sea Ice	AK	P-3						↔														
CALIPSO Val	VA VA, DFRC	Learjet, J-31 Learjt, DC-8							↔	↔			↔									
Water & Energy Cycle																						
MODIS Val	OK, TX OK, TX	ER-2 ER-2			↔			↔	↔													
SMEX	Western U.S. U.S.	P-3 P-3				↔			↔	↔												
CLPX	CO CO	DC-8, P-3? DC-8, P-3?										↔				↔						
Weather																						
TSCP	Costa Rica	DC-8, ER-2, WB-57, Prot, UAV							↔													
NPP/NPOESS Val		ER-2, Proteus?															↔					
Carbon Cycle & Ecosystems																						
NACP	U.S.	P-3, DC-8, Citation							↔													
Solid Earth																						
Earthscope																						

Table 4: 5-Year Plan

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Appendix:
Acronyms

AASI	Antarctic Sea Ice Campaign
ACES	Altus Cumulus Electrification Study
ACMAP	Atmospheric Chemistry Modeling and Analysis Program
ADEOS-II	Advanced Earth Observing System
AirMISR	Airborne Multi-angle Imaging Spectroradiometer
AirSAR	Airborne Synthetic Aperture Radar
ALTM	Airborne Laser Terrain Mapper
AMSR	Advanced Microwave Scanning Radiometer
AMSR-E	Advanced Microwave Scanning Radiometer - EOS
AOCI	Airborne Ocean Color Imager
ARC	Ames Research Center
ASAR	Advanced Synthetic Aperture Radar
ASF	Airborne Sensor Facility
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATM	Airborne Topographic Mapper
AVIRIS	Airborne Visible Infrared Imaging Spectrometer
BPA	Blanket Purchase Order
CARTA	Costa Rican Airborne Research and Technology
CFIT	Controlled Flight Into Terrain
CLPX	Cold Land Processes Field Experiment
CPL	Cloud Physics Lidar
CRT	Cathode Ray Tube
DEMs	Digital Elevation Models
DFRC	Dryden Flight Research Center
DICE	DC-8 Inlet/Instrument Characterization Experiment
DOE	Department of Energy
EFIS	Electronic Flight Instrumentation System
EOS	Earth Observing System
ERAST	Environmental Research Aircraft and Sensor Technology
ESE	Earth Science Enterprise
ESPO	Earth Science Project Office

FY	Fiscal Year
FR	Flight Requests
GPM	Global Precipitation Mission
GPS	Global Positioning Signal
GSFC	Goddard Space Flight Center
ICESat	Ice, Cloud and Land Elevation Satellite
INTEX-NA	InterCONTINENTAL Chemical Transport Experiment-North America
IR	Infrared
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
LAASP	Low Altitude Airborne Science Program
LARC	Langley Research Center
LIDAR	Light Radar
LOC	Loss of Control
LRR	Lightweight Rain Radiometer
LTI	linear time-invariant
MAC	Multi-Instrument Aircraft Campaign
MAMS	Multispectral Atmospheric Mapping Sensor
MISR	Multi-angle Imaging Spectroradiometer
MODIS	Moderate-Resolution Imaging Spectrometer
MSFC	Marshall Space Flight Center
NAFKW	Naval Air Facility Key West
NASDA	National Space Development Agency of Japan
NASA	National Aeronautics and Space Administration
NAST-I	NPOESS Aircraft Sounding Testbed Interferometer
NAST-M	NPOESS Aircraft Sounding Testbed Microwave Radiometer
NIMA	Natiional Imagery and Mapping Agency
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NPOES	National Polar Orbitiing Operational Environmental Satellite
NPOESS	NPOES + System
NSF	National Science Foundation
PI	Principal Investigator
PoleScat	Polarimetric Scatterometer
PSC	polar stratospheric clouds
SAGE III	Stratospheric Aerosol and Gas Experiment

SeaWIFS	Sea-Viewing Wide Field-of-View Sensor
S-HIS	Scanning High Resolution Interometer Sounder
SMEX	Soil Moisture Experiment
SOLVE	SAGE III Ozone Loss and Validation Experiment
SSM/I	Special Sensor Microwave Imager
SST	Sea Surface Temperature
STOL	short take-off and landing
SVS	Synthetic Vision Systems
TAWS	Terrain Awareness and Warning Systems
THORPEX	The Observing-System Research and Predictability Experiment
TIR	Thermal Infrared
TMS	Thematic Mapper Simulator
TRACE-P	Transport and Chemical Evolution over the Pacific
TRMM	Tropical Rainfall Measuring Mission
UARP	Upper Atmosphere Research Program
UAVs	Uninhabited Aerial Vehicles
UHF	Ultra High Frequency
USAF	U.S. Air Force
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VIIRS	Visible Infrared Imaging Radiometer Suite
VINTERSOL	Validation of International Satellites and Study of Ozone Loss
WFF	Wallops Flight Facility
WindRad	Wind Radiometers
WMO/WWRP	World Meteorological Organization/World Weather Research Program